CAN TIDAL DISRUPTION ENHANCE THE POPULATION OF SMALL EARTH-APPROACHING OBJECTS?. W. F. Bottke, Jr., *Caltech 170-25, Pasadena CA 91125, USA, bottke@kepler.gps.caltech.edu,* D. C. Richardson, *Box 351580, University of Washington, Seattle WA 98185, USA*, S. G. Love, *Caltech 252-21, Pasadena CA 91125, USA.*

Abstract

Asteroids or comets making close approaches to the Earth (or Venus) may undergo tidal disruption, producing numerous fragments which can be tens of meters in diameter or larger. To quantify this mass loss, we simulated encounters between rotating, strengthless, elongated, particulate bodies ("rubble-piles") and the Earth using an N-body code. By folding these results into a second code which models the evolution of Earth-crossing objects (ECOs) statistically, we found that the amount of mass removed by tidal forces per year was comparable to the main-belt injection rate of 50 m sized bodies into the 3:1 and ν_6 resonances. Thus, our results suggest that tidal disruption plays an important role in maintaining the steady-state fraction of small ECOs.

Introduction

It has been estimated that there are at least $\sim 10^6$ objects with diameters of 50 m or larger in the Earth-crossing object (ECO) population [1]. The lifetime of ECOs against planetary collision, ejection, or comminution is only $\sim$ 10-30 Myr [2], far shorter than the age of solar system (4.6 Gyr), such that this population must be constantly replenished to remain in steady-state. The primary source for this replenishment is thought to be the main-belt, where collisions between asteroids often deliver fragments to either the 3:1 mean-motion resonance with Jupiter or the ν_6 secular resonance. It has been estimated that roughly one 50 m object per year is injected into these orbits [3]. Once inside, these bodies undergo orbital evolution which can transport them to the terrestrial planet region via chaotic increases to their eccentricity [4]. It is thought that $\sim$ 10% of this population is removed from these resonances by perturbations from the Earth, Venus, or Mercury, enough to keep the ECO population in steady-state [3]. The exact percentage, however, is unknown.

We suggest that this scenario may miss an important source for small bodies in the ECO region. Weak bodies (i.e. "rubble-piles") residing here may be vulnerable to disruption by tidal forces during close encounters with the Earth or Venus. Because close planetary encounters occur more frequently than collisions, tidal disruption is capable of producing many small bodies, possibly enhancing the population of small bodies near Earth. Interestingly, these disruptions are most likely to take place where a large population of small ECOs has been suggested by D. Rabinowitz [5] (Details are given below).

Tidal Disruption Results

To investigate this issue, we model the tidal disruption of rubble-pile progenitors making close encounters with Earth. Our model, our assumptions, and our results are described in an accompanying LPSC abstract [6] (In particular, see Fig. 1 of that abstract).

Our results show four different tidal disruption regimes, the first three which produce small ejecta fragments (Fig. 1).

(S) "SL9-type" catastrophic disruption where the progenitor forms into a line of roughly equal size clumps (i.e. a "string of pearls") and leaves less than 50% of its mass in the largest fragment.

(B) Break-up with mass shedding of clumps and single particles, leaving the progenitor with 50%–90% of its original mass. Most of the mass is shed near the ends of the object, which is stretched due to tidal forces.

(M) Mild mass shedding of clumps or particles, leaving the progenitor with over 90% of its original mass. Similar to the B-class, M-class disruptions can cause the progenitor to become quite elongated, which may explain the strange shapes of several ECOs [7].

(N) No mass loss (but possible reshaping of the progenitor accompanied by spin-up or spin-down).

In general, we found that progenitors with fast spin rates, low encounter velocities, or those that make close encounters with Earth tend to undergo more catastrophic tidal disruptions.

Production of Small Bodies

To estimate the rate of mass loss due to tidal disruption near the Earth, we combined our results for tidal disruption over probability distributions for the progenitor's close approach distance to Earth (q), its encounter velocity "at infinity" (v_∞), and its rotation period (P). The probability distribution for ECO encounter velocities with Earth can be found in [8]. The probability distribution for ECO rotation periods can be estimated using the results found in [9]. The encounter probability for ECOs making a close approach to Earth can be estimated using the results of [8] and by calculating the gravitational focussing factor for each body. Finally, to determine how many ECOs are capable of undergoing tidal disruption, we combined the ECO size-frequency distribution reported in [1] with an estimate of the smallest rubble-pile theoretically possible (250 m; reported in [10]).

Pulling these components together, we estimated that the total mass shed by ECOs larger than 250 m in diameter is $\sim 6 \times 10^{10}$ grams per year. Tests show this result is relatively insensitive to changes on either end of the ECO size-frequency distribution (i.e. making the smallest rubble-pile diameter larger than 250 m, or eliminating several of the largest ECOs).

If we were to place all the mass shed in tidal disruptions into spherical objects 50 m across, the size of the object needed to produce a "Tunguska"-type event on Earth, their production rate would be 0.4 per year, comparable to the injection rate of similarly-sized bodies entering the 3:1 or ν_6 resonances from the main-belt [3].

Our results show that, on average, the lifetime of a rubble-pile against S class events is 450 Myr, the lifetime against a S or B class events is 260 Myr, and the lifetime against S, B, or M class events is 120 Myr. Thus, if we assume there are 2100 km-sized ECO's [1], S-type events should occur near the Earth once every 210,000 years, S and B events once every 120,000 years, and S, B, M events once every 55,000 years.

Since neither the size distribution of component material in a rubble-pile asteroid nor the supply rate of 50 m bodies from the main-belt to the ECO population are known, it is difficult to say which source is more important for replenishing the small ECOs.

Evidence for Tidal Disruption

We expect more tidal disruption where v_∞ values with the Earth are low. These regions should contain a greater abundance of tidal ejecta, since any material stripped from the progenitor will have orbital parameters similar to that of the progenitor (at least until planetary close encounters cause the bodies to spread).

To find these low v_∞ regions, we mapped v_∞ values for test objects encountering the Earth at regularly spaced (a, e, i) intervals using the technique of [8]. Fig. 2 shows two velocity contour maps taken from our results. Fig. 2a shows that test bodies with 5° inclination have low v_∞ values where e is small and periapse (q) and apoapse (Q) are near 1 AU. Fig. 2b shows a similar trend, though the higher inclination ($i = 20°$) raises the lowest v_∞ level enough to inhibit most tidal disruptions.

Thus, we predict that tidal ejecta should be common in low e, i regions near the Earth, the same region where Spacewatch has been finding many small ECOs [5]. Previous work has shown that this population cannot be easily be produced by alternative sources [11].

Does this result, however, match observations? A qualitative examination of the orbital distribution of 197 ECOs reveals few large bodies but many small bodies at low e, i. Though we cannot yet claim that tidal disruption is the sole culprit for this distribution of material, it is, at least, consistent with idea that tidal disruption plays a prominent role in the evolution of many ECOs.

References: [1] Morrison, D., Ed. (1992) *The Spaceguard Survey. Report of the NASA near-Earth object detection workshop.* NASA, Washington, D.C. [2] Milani, A., M., et al. (1989) *Icarus* **78** 212; Michel, P., et al. (1996) *Earth, Moon, and Planets 72*, 151; [3] Menichella, M., et al. (1996) *Earth, Moon, and Planets* **72**,133; [4] Wisdom, J. (1983) *Icarus* **56**, 51; [5] Rabinowitz, D. L. et al. 1993 *Nature* **363** 704; [6] Bottke, W. F., et al. (1997) This volume. [7] Solem, J. C, and J. G. Hills (1996) *Astron. J.* **111**, 1382; [8] Bottke, W. F., et al. (1994) In *Hazards Due to Comets and Asteroids*, U. Arizona Press, 337; [9] Harris, A. W. (1996) *Lunar Planet. Sci.* **27**, 493. [10] Love, S. G., and T. J. Ahrens (1996) *Icarus* **124**, 141; [11] Bottke, W. F., et al. (1996) *Icarus* **122**, 406.

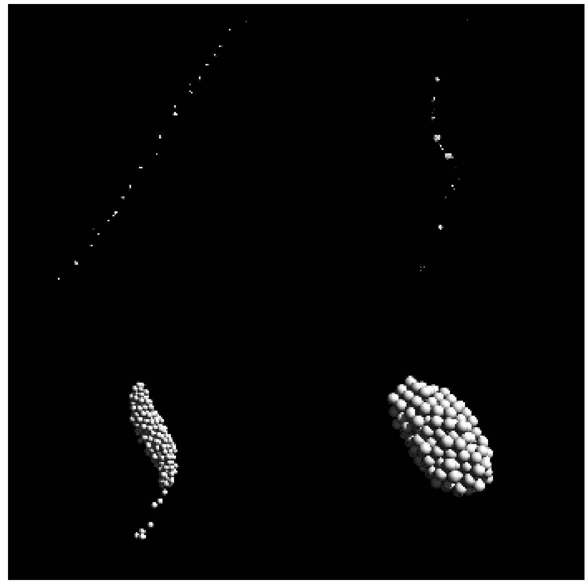

Figure 1: Snapshots of four classes of tidal disruption: Upper left (S), Upper right (B), Lower left (M), Lower right (N). See text for definitions.

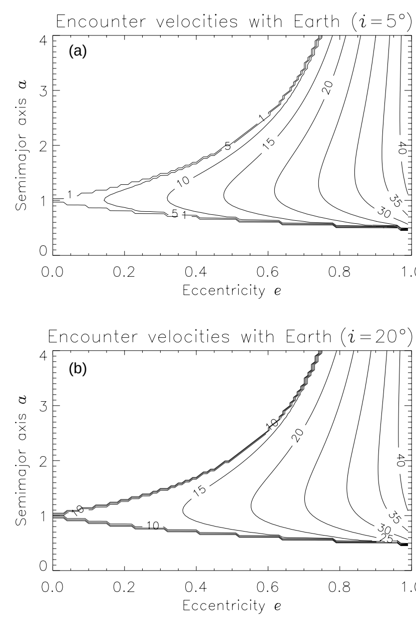

Figure 2: Contour plots in (a, e) space of mean v_∞ values for test bodies encountering the Earth with (a) $i = 5°$, and (b) $i = 20°$. Contours have units of km s^{-1}. The lowest velocities are found where e is small and periapse (q) and apoapse (Q) are near 1 AU.